

THE GEOLOGY AND METAMORPHISM OF THE BONNIE DOON AREA, VICTORIA

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ABSTRACT: The 2500 m Siluro-Devonian Bonnie Doon Formation, comprising mainly quartz sandstones and mudrocks, is conformably overlain by 250 m of lithic sandstone and conglomerate of the Glen Creek Lithic Sandstone north of Bonnie Doon. The oldest units outcrop in the west along the N-S trending Mt Easton Anticlinorium, while the Glen Creek Lithic Sandstone is confined to the Walhalla Synclinorium further east. These two formations are near the top of the Lower Palaeozoic Melbourne Trough sequence and have undergone low grade regional metamorphism producing monoclinic chlorite — 2M muscovite \pm carbonate assemblages. Metamorphism is interpreted to have been at very shallow depths requiring a high geothermal gradient, presumably associated with the onset of regional igneous activity. In the lithic sandstones, chlorite — carbonate assemblages formed instead of Ca-Al silicates as a result of significant $p\text{CO}_2$ (partial pressure of CO_2) during the regional event. Both sedimentary formations have been mapped within the aureole of the Late Devonian Strathbogie Granite, where four metamorphic zones are differentiated in pelitic metasediments: Spotted Zone, Biotite Zone, Cordierite-Muscovite Zone, Cordierite-K-Feldspar Zone. Granite intrusion took place under low confining pressure (≈ 0.5 kb). During thermal metamorphism, $p\text{H}_2\text{O} = p\text{Total}$ in the quartz-rich sandstones and mudrocks, but CO_2 was an important fluid component in the impure limestone conglomerates and many lithic sandstones.

Gold is most strongly developed within the cordierite hornfelses (often graphitic) near the Strathbogie Granite. It is finely disseminated through retrogressed pelites with rare quartz veins. Gold deposition from circulating aqueous solutions was associated with retrograde sericite alteration of surrounding host rocks.

INTRODUCTION

Bonnie Doon is situated on the northern edge of the Melbourne Trough. The stratigraphy of this trough has been described further south near Eildon (Thomas 1947) and Warburton (VandenBerg 1975). Much of the Trough comprises a rather uniform quartz-rich flysch sequence of sandstones, mudstones and shales of several thousand metres thickness (Schleiger 1964). However, near Bonnie Doon a major change of depositional environment is evident near the top of the sequence, with the incoming of lithic sandstones, conglomerates and lesser calcareous lithologies (Fig. 1).

The relatively wide range of bulk rock compositions has made possible a larger variety of contact metamorphic assemblages than is usual in Melbourne Trough aureoles: cf. Morang (Edwards & Baker 1944), Lysterfield (Phillips 1976). This has allowed a detailed reconstruction of the contact metamorphic conditions, which, coupled with a concurrent study of the Strathbogie Granite (Birch *et al.* 1977) yields a clearer understanding of the emplacement of alumin-

ous (S-type) granites in Central Victoria (Phillips *et al.* in prep.). The Tallangalook gold mine within the Bonnie Doon contact aureole is unusual for Victoria in being a disseminated deposit, exhibiting few quartz veins and bearing a close spatial relationship to a major intrusion (Dunn 1917, Kenny 1937).

This study has three main aims:

1. an interpretation of the stratigraphy and structure at Bonnie Doon,
2. a detailed investigation of contact metamorphic conditions, and
3. the construction of a model for gold genesis at Tallangalook.

The study also provides an explanation for some of the differences between pelitic assemblages developed in contact aureoles of the Melbourne Trough, and those in Ordovician metasediments further west.

REGIONAL GEOLOGY

The Melbourne Trough is a structural block containing mostly marine, Cambrian to Middle Devo-

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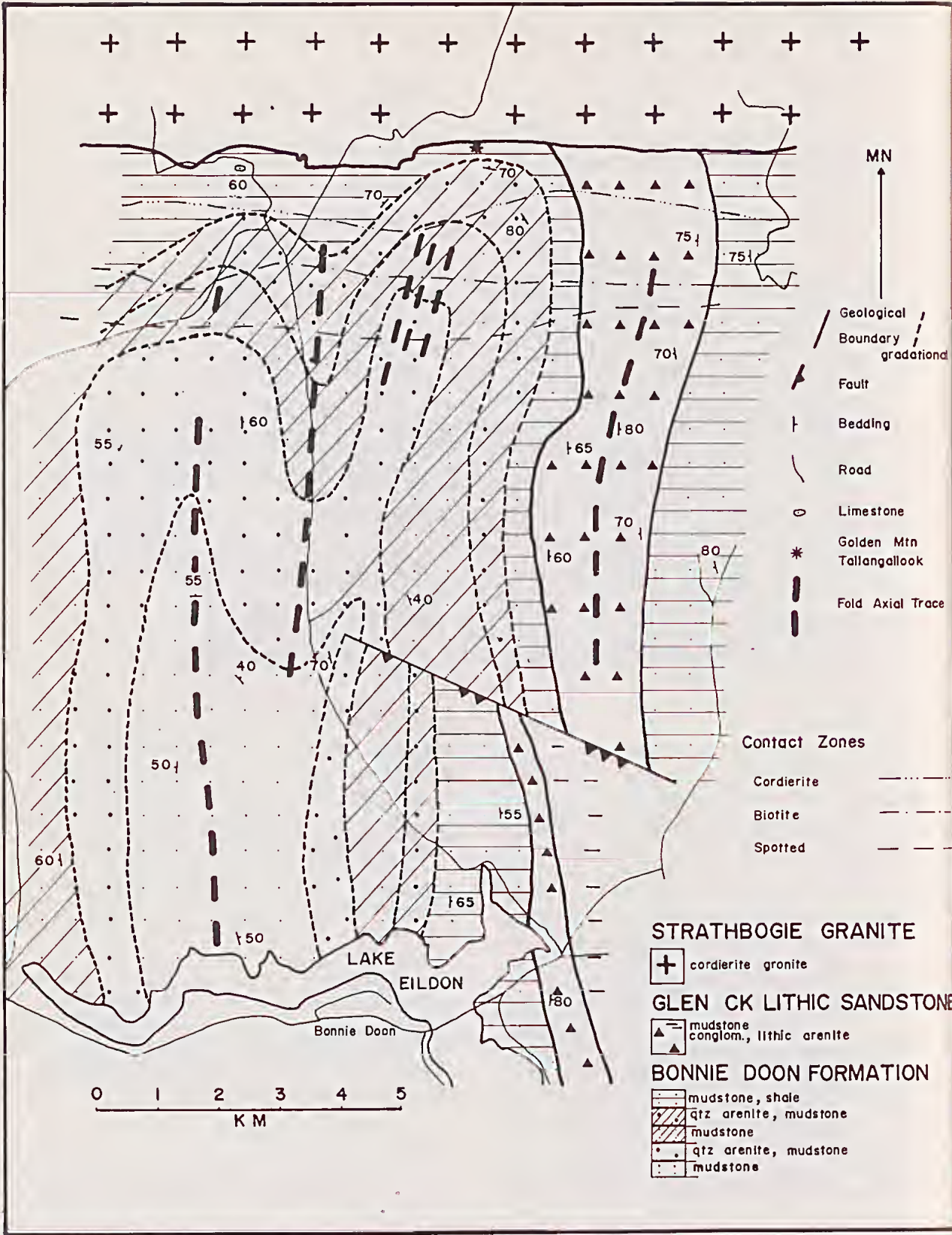


Fig. 1.—Palaeozoic geology of Bonnie Doon, Victoria.

nian sediments (VandenBerg & Garratt 1976). Sandstones and mudstones (terminology of Ingram 1953) of Siluro-Devonian age predominate throughout the exposed sequence and marker horizons are typically rare.

The regional structure consists of a series of NNW trending folds (Williams 1964) of which the Mt Easton Anticlinorium and Walhalla Synclinorium are considered by us to be the most important structures near Bonnie Doon. Folding is generally correlated with the Late Devonian Tabberabberan Orogeny (Talent 1965).

Within the Trough, the oldest beds are exposed in the west at Costerfield and Deep Creek (VandenBerg & Garratt 1976). In these areas Lower Palaeozoic sedimentation appears to have ceased in the Late Silurian or Early Devonian whilst further east, sedimentation continued through the Early Devonian and well into the Middle Devonian e.g. at Eildon and Upper Yarra (Moore 1965). The youngest Trough sediments (Cathedral Beds and Koala Creek Beds) are found between the latter two areas. These observations suggest a filling of the Trough, beginning in the west, during the Early Devonian.

Two formations have been defined in the Bonnie Doon area (see Appendix) and to the north these are intruded by the 2000 km² massive Late Devonian Strathbogic batholith.

STRUCTURE

Between Bonnie Doon and the Strathbogic Granite, the major structures are an anticlinorium in the west and a synclinorium in the east (Fig. 1). The folds trend N-S, have variable but generally shallow

plunges and near vertical axial planes. The anticlinorium is the northward extension of the Mt. Easton Anticlinorium (Mt Easton Axis of Thomas 1947) mapped near Eildon (VandenBerg 1975); the synclinorium is the northward extension of the Walhalla Synclinorium that extends south past Woods Point.

Associated with these major structures are numerous open to isoclinal minor folds with locally overturned bedding. Whereas bedding is usually preserved, a weak axial plane cleavage is widespread in the finer lithologies. A NW-SE striking hinge fault cuts through the centre of the area, downthrowing sediments on the south.

The major structures can be traced into the contact aureole with some difficulty, and are abruptly truncated by the granite. The contact itself is sharp, and detailed mapping shows it is steeply dipping (Birch *et al.* 1977, Phillips *et al.* in prep.).

SEDIMENTARY PETROGRAPHY

Quartz Sandstone

The quartz sandstones consist of moderately sorted, subangular to rounded quartz grains (0.1-0.5 mm), that show variable degrees of grain boundary adjustment. Grains are often interlocking, have sutured edges and the rocks have no visible porosity. Angular feldspar and lithic fragments, made up > 10% of some samples (Table 1).

Matrix material (5-20%) is mainly chlorite and elongate aggregates of white mica. The latter are bent around quartz grains and define a weak foliation parallel to bedding.

TABLE 1
MINERALOGY OF MELBOURNE TROUGH SEDIMENTS: BONNIE DOON FORMATION AND GLEN CREEK LITHIC SANDSTONE.

	<i>Quartz Sandstone</i>	<i>Mudrocks</i>	<i>Lithic Sandstone</i>	<i>Conglomerate</i>
COARSE DETRITAL FRACTION	Quartz	Quartz	Quartz	Quartzite
	K-Feldspar	Mica	Feldspars* (5-20%)	Sandstone
	Na-Plagioclase		Shale (5-30%)	
	Granite (r)		Quartzite	
			Alt. Mafic Voles	
		Mica schist (r)		
MATRIX	White mica	White mica	White mica	Quartz
	Chlorite	Chlorite	Chlorite	Sandstone
	Quartz	Carbonaceous matter	Carbonate (r)	Quartzite
	Tourmaline		Tourmaline	
	Rutile (r)	Sulphides (r)	Carbonaceous matter	
CEMENT	Calcite (XRD) (< 30%)	Carbonate (< 2%)	Carbonate Silica	Silica Fe oxide (?weathering)

r = rare, *: alkali and sodic feldspar.

Mudrocks (Mudstones, Shales)

The mudstones consist of a silt sized, quartz-rich, clastic fraction set in a chlorite-white mica matrix. The shales contain mainly monoclinic chlorite and 2M muscovite (somewhat phengitic) with little quartz.

Lithic Sandstones

The lithic sandstones have a variable texture and mineralogy. Most are poorly sorted, angular, coarse to fine sand varieties that lack fine scale bedding. Quartz and feldspar are the main framework components, along with common shale fragments up to 1 cm. The latter contain quartz, chlorite and white mica. Other lithic fragments comprise altered mafic volcanics, quartzites and mica schists. Matrix material is mainly chlorite and white mica.

POST-DEPOSITIONAL MODIFICATION OF THE MELBOURNE TROUGH ROCKS

Since the younger sediments at Bonnie Doon appear to be near the top of the Melbourne Trough sequence, it is unlikely they were ever buried to a depth greater than 5000 m (see also later discussion). However, most of the sediments have undergone substantial post-depositional textural and mineralogical adjustments. The coarse grained sediments have undergone compaction and grain boundary adjustment which in extreme cases have partially obliterated the clastic nature of the rocks. The finer grained sediments show little adjustment of framework grains, but show a preferred orientation of phyllosilicates parallel to bedding within the matrix.

Mineralogical changes are most pronounced in the mudrocks and lithic sandstone matrix. From their present mineralogy the mudrocks have a bulk chemistry (Si, Al, K, Mg, Fe rich; Na, Ca poor) indicative of a quartz-illite-chlorite \pm montmorillonite \pm kaolinite sediment. The present mineralogy involves quartz and detrital white mica along with post-depositional chlorite, 2M white mica, carbonates, minor sulphide and carbonaceous material (Table 1). These secondary mineral assemblages and those from underlying Cambrian metavolcanics (see below) are compatible with upper zeolite-prehnite/pumpellyite grade regional metamorphic adjustment of the sequence (Frey 1970). Similar secondary assemblages have been noted elsewhere in the Melbourne Trough at Sugarloaf Dam-site, in Early Devonian-Silurian siltstones (Diprose 1976). The metamorphic adjustments presumably took place during burial and deformation associated with the Tabberabberan Orogeny.

Ordovician rocks outcropping 40 km southeast of Bonnie Doon on the Howqua River exhibit well developed slaty cleavage. This sequence abuts Camb-

rian (?) mafic volcanic and intrusive rocks which contain combinations of prehnite, pumpellyite and actinolite (Bailey 1974, Herrmann 1974). If these early Palaeozoic sequences are presumed to underlie the Melbourne Trough sequences, then low grade metamorphic assemblages in the Cambrian-Ordovician rocks may also reflect the Tabberabberan Orogeny. However it has not been conclusively demonstrated that the Siluro-Devonian rocks conformably overlie the Ordovician. Furthermore, mafic volcanic detritus in the Glen Creek Lithic Sandstone may have a Cambrian source (see below), pointing to uplift of greenstone belts before sedimentation ceased in the Melbourne Trough.

The absence from the Glen Creek Lithic Sandstone of calcsilicate phases characteristic of low grade metamorphic facies (e.g. zeolites or pumpellyite) may be due to the activity of carbon dioxide. Even at low $p\text{CO}_2$, these phases are unstable relative to carbonate-chlorite assemblages (Zen 1961) such as those at Bonnie Doon and Sugarloaf Dam (Diprose 1976). However, the presence of sphene in the secondary mineral assemblages of the sediments indicates that $p\text{CO}_2$ was below that required for the development of rutile + calcite (Hunt & Kerrick 1977). The absence of hematite and the common presence of sulphides suggest generally reducing conditions during the low grade regional adjustment.

DEPOSITIONAL ENVIRONMENT

The sedimentary structures, absence of fossils and textural immaturity of the coarser sediments at Bonnie Doon suggest deposition from turbidity currents as envisaged by Schleiger (1971). The large proportion of mudstone and shale in the Bonnie Doon Formation further suggests distal deposition with significant periods of intervening pelagic sedimentation. The conglomerates near the top of the sequence mark a change from quartz-rich flysch (Bonnie Doon Formation) to an intermediate flysch (Glen Creek Lithic Sandstone). There is no evidence of shallowing of water depth, and we favour an allochthonous origin for the limestone conglomerate. The quartz-rich conglomerate at the base of the Glen Creek Lithic Sandstone is also surrounded by deep water flysch sediments and may represent a submarine channel deposit.

PROVENANCE

The quartz-clay rich, pre-burial character of the Siluro-Devonian sequence suggests that the source area for these sediments comprised older granitic plus sedimentary and/or metamorphic terranes. Such areas may have been exposed to the west and south of the Melbourne Trough, though the picture is less clear to

the east. Although the surrounding Lower Palaeozoic sequences have provided some detritus (e.g. Cambrian (?) altered mafic volcanic fragments, Ordovician slate fragments) for the Glen Creek Lithic Sandstone, the Lower Palaeozoic contribution to the bulk of the sequence is not readily apparent. A pre-Ordovician terrane to the west and/or south of the Melbourne Trough seems the most likely source area, in accord with palaeo-current directions (Couper 1965). This could have contributed the bulk of the quartz and clays and also the rarer mica schist fragments. Studies of assemblages from gneissic xenoliths in Central Victorian igneous bodies have suggested an underlying high grade regional metamorphic terrane e.g. sillimanite-garnet, sillimanite-biotite-ilmenite, cordierite-spinel from the Violet Town Volcanics, cordierite-ilmenite, sillimanite-spinel-garnet from the Strathbogie Granite (Birch *et al.* 1977) and Cerberean Cauldron (Birch & Gleadow 1974).

The Siluro-Devonian pelites such as those at Bonnie Doon have higher chlorite/mica ratios than Ordovician pelites. The younger rocks are hence generally less aluminous with higher (Fe + Mg)/Al. This suggests that the source area of the Early Devonian sediments may have been less intensively weathered

than that of the Ordovician sediments leading to less degraded clay assemblages — perhaps resulting from cooler climates and Australia's poleward post-Ordovician movement (Embelton *et al.* 1974).

CONTACT METAMORPHISM

PETROGRAPHY

A broad contact metamorphic aureole (up to 3 km wide) developed north of Bonnie Doon along the margin of the Strathbogie Granite (Phillips *et al.* in prep.). This batholith comprises mainly massive cordierite-biotite granites and has sharp steeply dipping contacts with the surrounding hornfelses. K/Ar dating of the granites gives cooling ages of 365 ± 5 my. (Richards, J. R., pers. comm. 1975).

Four metamorphic zones have been mapped in pelitic lithologies: (a) Spotted, (b) Biotite, (c) Cordierite-Muscovite, (d) Cordierite-K-Feldspar. Assemblages observed in these zones are listed in Table 2.

Spotted Zone: The first mesoscopic signs of contact metamorphism are spotting on the bedding planes of pelites. The spots are marked by slight modal increase

TABLE 2
PROGRADE CONTACT METAMORPHIC ASSEMBLAGES IN SILURO-DEVONIAN SEDIMENTS ADJACENT TO
THE STRATHBOGIE GRANITE, NORTH OF BONNIE DOON.

	<i>Spotted Zone</i>	<i>Biotite Zone</i>	<i>Cord-Musc Zone</i>	<i>Cord-Kfs Zone</i>
PELITIC	Musc-Chl-Qtz \pm Tour, Opaq.	Bi-Musc-Chl-Qtz \pm Tour, Fe oxide, Sulphide, Zircon, Graphite, Na Plag.	Cord-Musc-Bi-Qtz- Tour-Opaq.	Kfs-Cord-Bi-Tour-Qtz- Opaq. \pm Musc
PSAMMITIC	Musc-Qtz \pm Tour	Musc-Qtz \pm Tour, Bi	Musc-Qtz \pm Tour, Bi	Musc-Bi-Tour-Qtz
CALCAREOUS	Not present	Diop-Cc-Plag Diop-Cc-Opaq-Qtz Diop-Cz-Opaq-Qtz Diop-Act-Sph-Qtz Diop-Plag-Op-Qtz Act-Cc-Op-Qtz Act-Plag-Ilm-Qtz-Bi	Diop-Trem-Opaq-Qtz Diop-Plag-Ilm-Qtz Diop-Cc-Plag-Qtz Diop-Cc-Op-Qtz Diop-Woll-Cc-Qtz Diop-Woll-Cc-Opaq Diop-Act-Qtz Diop-Act-Cc Act-Bi-Plag-Ilm-Qtz Act-Cc-Qtz Woll-Scap-Cc-Sph Woll-Diop-Vesuv-Qtz	Not present

KEY	Tour = Tourmaline	Ilm = Ilmenite	Scap = Scapolite
Bi = Biotite	Opaq = Opaque phase	Diop = Diopside	Sph = Sphene
Musc = Muscovite	Cord = Cordierite	Cc = Calcite	Trem = Tremolite
Qtz = Quartz	Plag = Plagioclase	Act = Actinolite	Vesuv = Vesuvianite
Chl = Chlorite	Kfs = K-Feldspar	Woll = Wollastonite	Cz = Clinozoisite

of chlorite, muscovite and opaque minerals. Neighbouring psammities retain their sedimentary and regional metamorphic microstructure. The Spotted Zone is up to 800 m wide.

Biotite Zone: Biotite-rich hornfelses with minor muscovite and chlorite are typical of this zone. Muscovite and fawn brown biotite have grown parallel to the poorly defined bedding. Calc-silicate phases occurring in the lithic sandstones include calcite, diopside, actinolite, tremolite, clinozoisite and plagioclase. Relict clastic microstructures are preserved and most of the metamorphic phases are fine grained (< 1 mm). The Biotite zone is up to 1.5 km wide.

Cordierite-Muscovite Zone: Within 1000 m of the granite, cordierite porphyroblasts up to 2 mm in diameter are abundant in pelitic hornfelses. These porphyroblasts are sector twinned with inclusions of biotite, quartz, muscovite and opaque minerals. The biotite has a similar habit to that of lower grade rocks, but is a medium brown colour in thin section. Psammities are typically well recrystallized exhibiting polygonal quartz grains and a weak inherited foliation defined by muscovite and biotite.

The impure limestone conglomerate, which forms a 50 m long pod, contains 5 mm by 15 mm calcareous lenses set in a more siliceous matrix. The lenses are flattened parallel to bedding, are wollastonite-rich and commonly have calcite cores. Quartz is rare but may coexist with wollastonite and calcite. The siliceous matrix contains diopside, scapolite, vesuvianite and quartz with rare shale fragments. The grain size within the calcareous and siliceous area is fine (< 1 mm).

Cordierite - K-feldspar Zone: Perthitic K-feldspar is found in fresh cordierite hornfelses within 100 m of the granite, marking the highest grade zone in the aureole. Muscovite is less abundant than at lower grades and chlorite is absent. In this zone, especially around the Golden Mountain quarries at Tallangalook, much pelite has been retrogressed to sericite-rich assemblages.

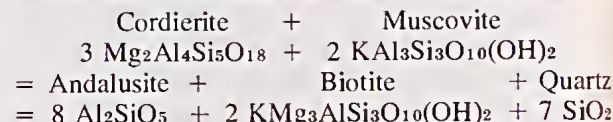
PETROGENESIS

The prograde metamorphic zonal pattern found in the Bonnie Doon aureole has long been recognised from other aureoles, e.g. Comrie (Tilley 1924) and Bulla (Tattam 1925). The abundance of cordierite and lack of garnet in these aureoles is evidence of pressures substantially less than commonly found in regional metamorphism.

However the Bonnie Doon assemblages differ slightly from those found in Ordovician hornfelses in

west-central Victoria. At Bendigo (Beavis 1962) and at Charlton, andalusite is associated with cordierite-muscovite-biotite hornfelses in Ordovician thermal aureoles. AFM and A'KF projections of these four phases in the presence of quartz (Fig. 2, 3) show that cordierite-muscovite assemblages can be chemically equivalent to biotite-andalusite assemblages. Thus the occurrence of andalusite assemblages could reflect differing p-t conditions. In highly aluminous metasediments andalusite may form with or without biotite, regardless of bulk rock Fe: Mg ratios.

In the Fe-free system $K_2O-MgO-Al_2O_3-SiO_2-H_2O$ (Seifert 1970, Bird & Fawcett 1973), the reaction:



has a large negative ΔV term (-3.013 cal/bar, Robie & Waldbaum 1968). As such, muscovite-cordierite would be the low pressure assemblage. From experimental studies biotite-andalusite-quartz would be favoured by higher pressure and temperature (Seifert 1970).

With the introduction of Fe, this reaction becomes divariant and cordierite-muscovite is restricted to even lower p and t. Thus three main factors favour the occurrence of andalusite in pelitic hornfelses: (1) highly aluminous compositions, (2) higher p and/or t within the andalusite stability field, (3) high Fe/Mg ratios. Bulk chemical and temperature controls on mineralogy are evident in some aureoles e.g. Bendigo (Beavis 1962), but the effect of pressure is difficult to assess while accurate pressure data within many aureoles are unavailable.

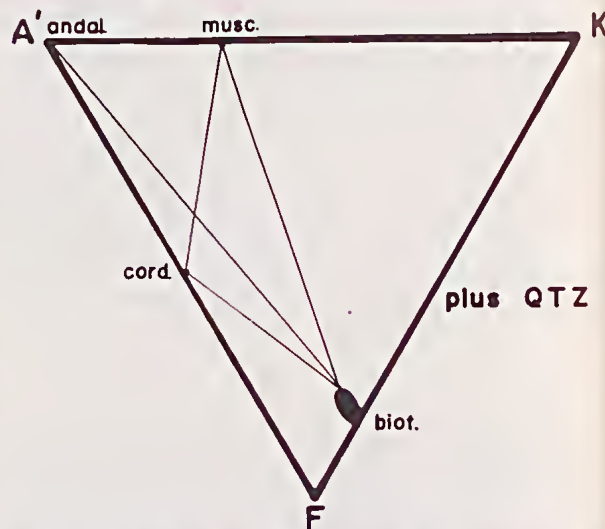


Fig. 2.—A'KF diagram illustrating the equivalence of biotite-andalusite and muscovite-cordierite assemblages.

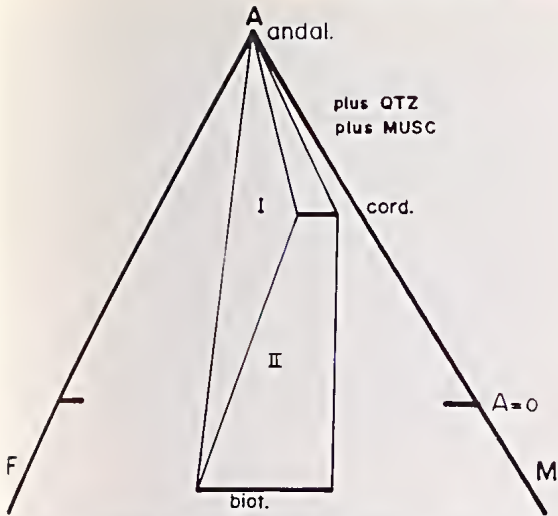


Fig. 3.—AFM diagram for Cordierite-Muscovite zone, showing the compositional field of andalusite-cordierite-biotite-muscovite-quartz (I) and the same assemblage without andalusite (II).

Pressure: A reasonable estimate of pressure within the Bonnie Doon aureole can be made from stratigraphic cover criteria, but the metamorphic assemblages offer little additional quantitative information. Two lines of stratigraphic evidence are available: the Violet Town Volcanics and the Siluro-Devonian sediments.

The Violet Town Volcanics abutting the northern margin of the Strathbogie Granite exhibit contact metamorphic effects. The granite intrudes the rhyodacite ignimbrite well above the base of the volcanic sequence. Hence this portion of the granite solidified at shallow depth — perhaps less than 1000 m. Providing there has been no large post-granite emplacement movement, the present Bonnie Doon aureole may represent structural levels only 500-1000 m below this.

The youngest sedimentary units exposed at Bonnie Doon (upper part of the Glen Creek Lithic Sandstone) are correlated with the Early-Middle Devonian Norton Gully Sandstone, which is itself near the top of the Melbourne Trough (VandenBerg & Garratt 1976). East of Bonnie Doon and in the Cathedral Range to the south, younger Devonian sediments overlie the Norton Gully Sandstone but these do not exceed 2000 m thickness (VandenBerg & Garratt op. cit.). Since the Strathbogie Granite (Late Devonian) has closely followed the cessation of sedimentation and the deformation of the Melbourne Trough sequence (Middle-Late Devonian) the likely depth of intrusion is therefore less than 2000 m. Thus stratigraphic considerations indicate aureole pressures of less than 1 kb, possibly less than 0.5 kb. Under such low confining pressures, the typical shallow positive slope (dp/dt) of

dehydration reactions would place these reactions at relatively low temperatures.

Temperature: High level intrusions are often associated with quite small aureoles since the surrounding country rocks are rather cool, yet the aureole around the Strathbogie Granite is up to 3 km wide. Detailed mapping at several places with up to 500 m relief repeatedly indicates a steep to vertical granite contact.

Phase equilibria give some indication of the likely temperature maximum, and its distribution in the contact aureole during intrusion. Within the pelites two isograds are particularly useful for estimating temperature: (1) the incoming of cordierite-muscovite, (2) the incoming of cordierite — K-feldspar. The temperature ranges for the Spotted Zone and Biotite Zone in other aureoles have been estimated by Turner (1968) and are included here (Fig. 4).

The breakdown of chlorite-muscovite-quartz assemblages has been studied by Seifert (1970), Hirschberg and Winkler (1968) and Bird and Fawcett (1973). Seifert, and Bird and Fawcett ran experiments in the Fe-free system and their results are mainly of qualitative interest here. Hirschberg and Winkler produced cordierite in unreversed runs at: 0.5 kbars \approx 525° C, 1.0 kbars \approx 515° C. The formation of cordierite — K-Feldspar assemblages has been studied by Haack (in Winkler 1967, p. 74). According to Winkler, temperatures for the reaction: Muscovite + Biotite + Quartz = Cordierite + K-Feldspar + H₂O are similar to the muscovite-quartz breakdown, i.e.: 0.5 kbars 580 \pm 10° C, 1.5 kbars 600 \pm 10° C. Obviously the muscovite-quartz breakdown places an upper temperature limit on the muscovite-biotite-quartz reaction, and hence cordierite formation by this reaction.

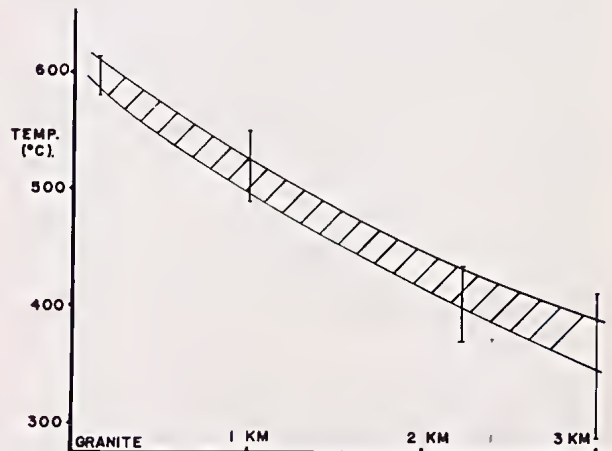


Fig. 4.—Maximum temperature in the Bonnie Doon contact aureole vs. distance from the Strathbogie Granite.

Jaeger (1957) calculated the theoretical temperature distribution around cooling intrusive bodies. According to his model, the Strathbogie Granite can best be approximated as a large (1+ km wide) granite body intruded into fluid-saturated sediments. To form such a large aureole with a contact temperature of 550-600°C requires an elevated country rock temperature (250-300°C) prior to intrusion. At an average geothermal gradient of 20°C/km the sediments would not have reached 100°C during burial. This suggests that the geothermal gradient in this part of the Melbourne Trough was significantly higher than average during the Late Devonian period of acid igneous activity, culminating in acid plutonism and volcanism.

Activities of Volatiles during Contact Metamorphism:

In the absence of data to the contrary, fluid pressure is regarded as approximating the total pressure for the following discussion.

The mineralogy of the mudstones and quartz sandstones suggest that a water-rich fluid phase existed in these lithologies during contact metamorphism. Variable but minor dilution by CO₂ and CH₄ seems likely, due to the oxidation with contact metamorphism of carbonaceous matter in the metasediments.

The local presence of carbonaceous material, the absence of hematite and the rarity of magnetite in the hornfelses imply generally low oxygen fugacities during contact metamorphism. More substantial dilution of aqueous fluids by CO₂ prevailed in the lithic sandstones and limestone conglomerate. The assemblage diopside and tremolite-calcite-quartz from the one locality imply locally varying pCO₂. In the Cordierite-Muscovite Zone, wollastonite bearing assemblages are common in the impure limestone conglomerate. Usually wollastonite forms a reaction layer between calcite lenses and the siliceous matrix, but where calcite-wollastonite-quartz coexist, xCO₂ limitations are implied.

Experimental studies with wollastonite (Harker & Tuttle 1956, Greenwood 1967) show the temperature of formation to be strongly dependent on fluid composition i.e. xCO₂. The apparent stable coexistence of wollastonite-calcite-quartz at some places and the presence of wollastonite or quartz-calcite at others within the one thin section, may indicate a variable xCO₂ over a few centimetres. Suggested limits for 550°C are: Wollastonite xCO₂ < 0.3, Calcite-Quartz xCO₂ > 0.3.

GENESIS OF THE GOLD DEPOSITS

Apart from minor amounts of cassiterite, the only significant mineralization around Bonnie Doon is gold. The major production came from the Golden

Mountain quarries at Tallangalook, totalling in excess of 142 kg of gold (Dunn 1917, Kenny 1937, Bowen 1974). Although gold mineralization is largely confined to the metasediments, major occurrences bear close spatial relationship to the Strathbogie Granite. Both the Tallangalook quarries and the Black Ore mine further west are within cordierite zone hornfelses and the only cordierite-K-feldspar assemblages have come from drill cores from the former location. Marginal dykes are present in some workings.

Tallangalook is situated on the nose of a broad, north-plunging anticline within 100 m of the granite. The bedding dips at 60-70° N towards the granite contact, which is sharp, steep, and associated with minor aplite dykes. Lithologies include cordierite-rich hornfelses, quartzites and some carbonaceous hornfelses, most of which are quite retrogressed. Gold occurs as fine disseminated grains with arsenopyrite and pyrite in carbonaceous pelites and on quartz films (Kenny 1937, Baragwanath 1937). Values were apparently lower in adjacent siliceous hornfelses. Throughout all the quarries and small mines, quartz veins are minor and bear no obvious relationship to higher gold grades.

Although the Melbourne Trough sediments are overall not particularly auriferous (Bowen 1974, Glasson & Keays 1978), it appears likely that they contributed to the Tallangalook mineralization. The outcropping granite is generally not marked by high gold values, whereas the Tallangalook stratigraphic horizon has small mining pits even out of the contact aureole. Our proposed model of gold genesis involves remobilization of gold by granite-initiated, circulating aqueous fluids followed by deposition at reducing sites, particularly at or near graphitic hornfelses. The widespread retrogression at Tallangalook may result from these aqueous fluids. The steep dip of the bedding towards the granite and/or the N-S faults may have provided a structural control over fluid movement.

APPENDIX

STRATIGRAPHY — MELBOURNE TROUGH ROCKS BONNIE DOON FORMATION

Derivation: Bonnie Doon town (985015, Alexandra, 1:100,000).

Type Section: North shore of Lake Eildon (939023 to 977020, Alexandra).

Lithologies: Quartz sandstone, siltstone, shale and rare limestone conglomerate.

Thickness: At least 2500 m, type section.

Age and Relations: This formation is the oldest exposed in the area and outcrops west of Dry Creek Road (Bonnie Doon to Tallangalook Road on Fig. 1) along the Mt. Easton Anticlinorium. The base is unexposed

but the top is marked by the incoming of conglomerates and lithic sandstones of the Glen Creek Lithic Sandstone above discontinuous dark shales.

The formation consists of a series of alternating massively bedded, dark green-grey mudstones and shales. Cross bedding (up to 2 cm) and graded bedding are common, while flame structures and ripple marks are found locally. The quartz sandstones weather to a red-orange colour in contrast to the brown-green weathered mudstones. Outcrop is poor except in the more massive sandstones.

On lithological similarities and general stratigraphy, the Bonnie Doon Formation is correlated with the Bullung Siltstone, Sinclair Valley Sandstone (both Middle-Late Silurian), Whitelaw Siltstone, Eildon Sandstone and Wilsons Creek Shale (all Early Devonian) of Thomas (1947) and VandenBerg and Garratt (1976). Quartz sandstone outcropping 1.5 km west of Bonnie Doon in the core of the Mt. Easton Anticlinorium may be equivalent to the McAdam Sandstone of VandenBerg and Garratt. This unit does not outcrop north of Lake Eildon.

GLEN CREEK LITHIC SANDSTONE

Derivation: Glen Creek (021031, Alexandra).

Type Section: (011075 to 027074, Euroa, 1:100,000).

Lithologies: Lithic sandstone, quartz sandstone, siltstone, shale and olistomictic conglomerate.

Thickness: 250 m, type section.

Age and Relations: The Glen Creek Lithic Sandstone conformably overlies the Bonnie Doon Formation and outcrops in the major synclinorium east of Dry Creek Road. The base of the formation is marked by discontinuous conglomerate lenses and lithic sandstone. The formation is overlain by unnamed mudstones to the east. Whereas poorly bedded, grey-green quartz sandstones and mudstones predominate, conglomerate and several units of grey lithic sandstone form mappable horizons. These latter are only 1-10 m thick but are usually continuous for hundreds of metres. On lithological grounds, the Glen Creek Lithic Sandstone is correlated with the Norton Gully Sandstone of the Walhalla Group (VandenBerg 1975). As in the Bonnie Doon Formation, lack of fossil evidence makes this correlation tentative.

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